

Transverse gluon structure of the proton and the black-disk limit in high-energy scattering

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[Details in: Ann. Rev. Nucl. Part. Sci. (2005), hep-ph/0507286]

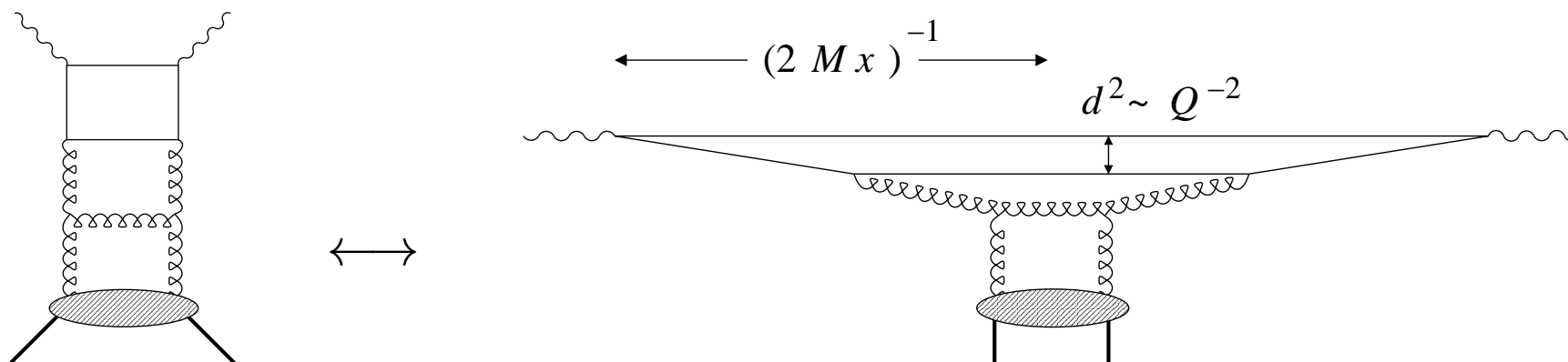
- Dipole-proton interaction in leading $\log Q^2$ inclusive /diffractive DIS at small x
- Transverse spatial distribution of gluons in proton t -dependence of hard exclusive vector meson production

→ “Black disk limit” of dipole-proton scattering

Implications for pp/pA at LHC
heavy ion collisions
cosmic ray physics

Talk by M. Strikman

- Dipole–proton interaction from QCD factorization [Brodsky et al. 94; Frankfurt, Radyushkin, Strikman 96]



LO DGLAP
 $\alpha_s \ln(Q^2/Q_0^2)$

\longleftrightarrow

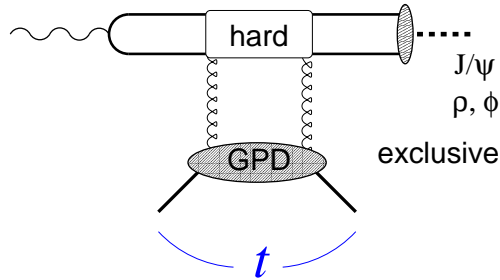
$$\sigma^{dp} = F_{\text{color}}^2 d^2 \alpha_s xG(x, Q_{\text{eff}}^2)$$

dipole–proton
 cross section

$$Q_{\text{eff}}^2 = \text{const} \times d^{-2}$$

- Gluon density well–defined: Leading–twist, DGLAP evolution
- Diffractive DIS: $q\bar{q}g \dots$ dipoles

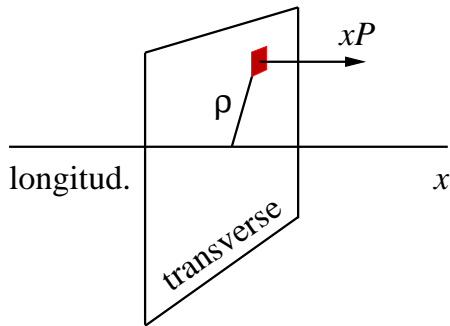
- Transverse spatial distribution of gluons



$$G(x, Q_{\text{eff}}^2; t) = G(x, Q_{\text{eff}}^2) \times F_g(x, Q_{\text{eff}}^2; t)$$

generalized
gluon dist'n

two-gluon
formfactor



$$F_g(x, t) = \int d^2\rho e^{-i\vec{\Delta}_\perp \cdot \vec{\rho}} F_g(x, \rho)$$

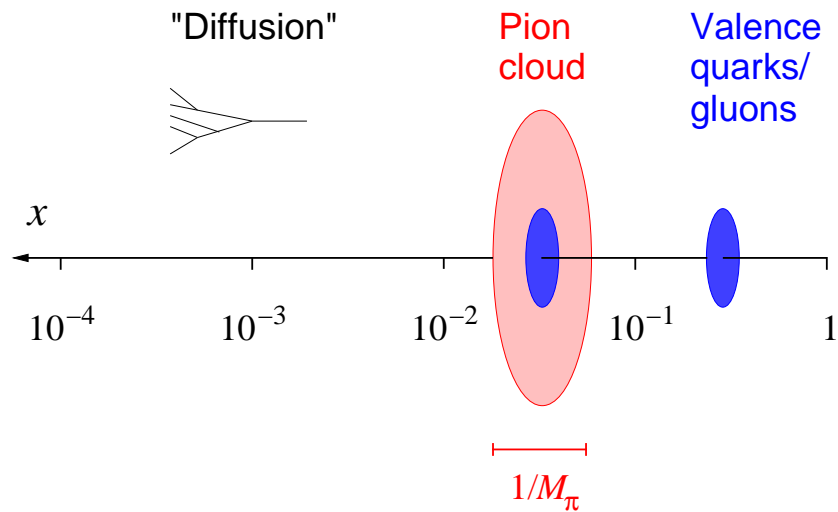
transverse
spatial
distribution
of gluons

$$\langle \rho^2 \rangle_g = 4 \frac{\partial}{\partial t} F_g(x, t)$$

gluonic transverse
size of nucleon,
 x -dependent!

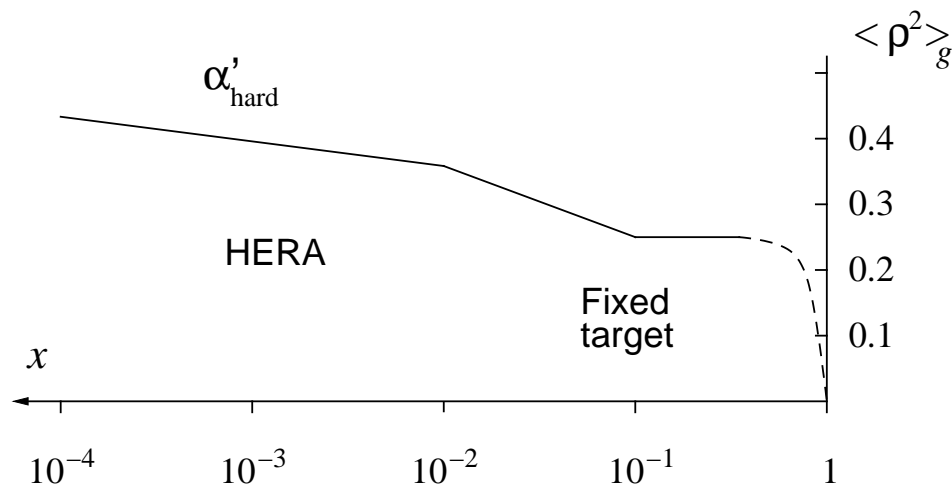
– Can be extracted from t -dependence of $\frac{d\sigma}{dt}(\gamma^* p \rightarrow V p)$

- Gluonic transverse size: x -dependence



- Gluonic transverse size increases with decreasing x

- Pion cloud contributes for $x < M_\pi/M_N$
[Strikman, CW 03]



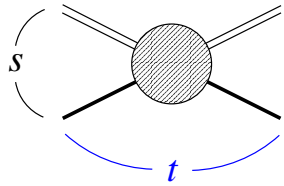
- Transverse size at large x much smaller than proton radius in soft interactions:

$$\langle \rho^2 \rangle(x > 10^{-2}) \ll R_{\text{soft}}^2$$

“Two-scale picture”

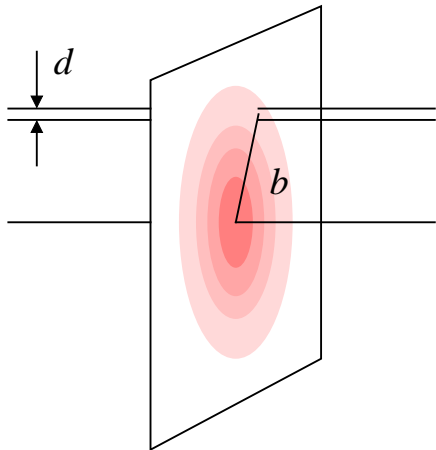
- Optics of dipole–proton scattering

[Frankfurt, Guzey, Strikman 02;
Frankfurt, Strikman, CW 03]



$$A^{dp}(s, t) = \frac{is}{4\pi} \int d^2b e^{-i\vec{\Delta}_\perp \cdot \vec{b}} \Gamma^{dp}(s, b)$$

dp elastic amplitude
in impact parameter
representation
($t = -\Delta_\perp^2$)



$$\sigma_{\text{el}}(s) \sim |A^{dp}|^2 = \int d^2b |\Gamma^{dp}(s, b)|^2$$

$$\sigma_{\text{tot}}(s) \sim \text{Im } A^{dp} = \int d^2b 2 \text{Re } \Gamma^{dp}(s, b)$$

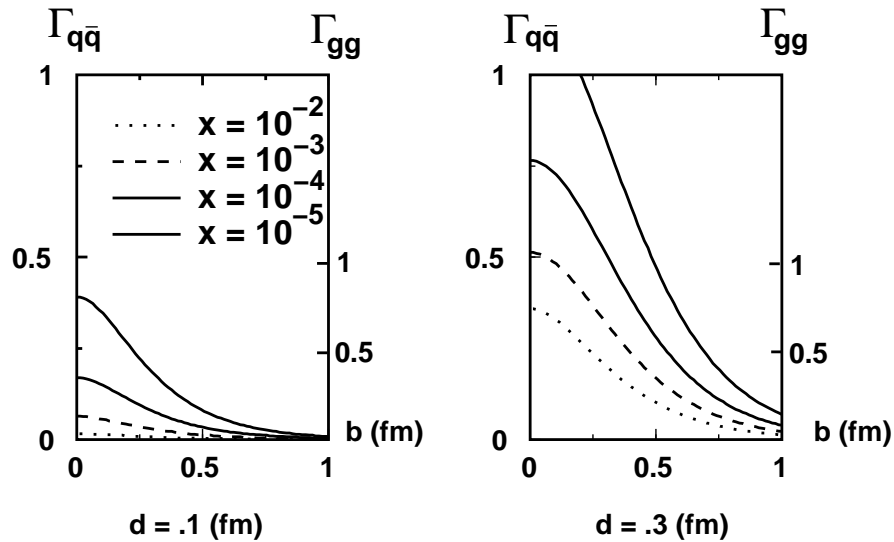
↓

$$\sigma_{\text{in}}(s) = \int d^2b \underbrace{\left[1 - |1 - \Gamma^{dp}(s, b)|^2 \right]}$$

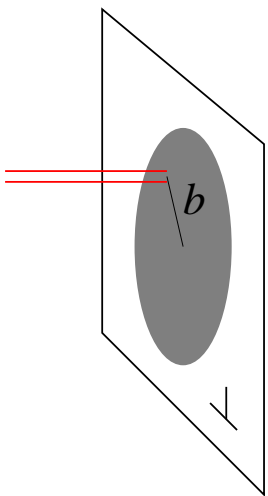
Probability of
inelast. interaction

- “Black disk” limit: $\Gamma^{dp} \rightarrow 1$
Unit probability for inelastic interaction

- Black disk limit (BDL) in dipole–proton scattering

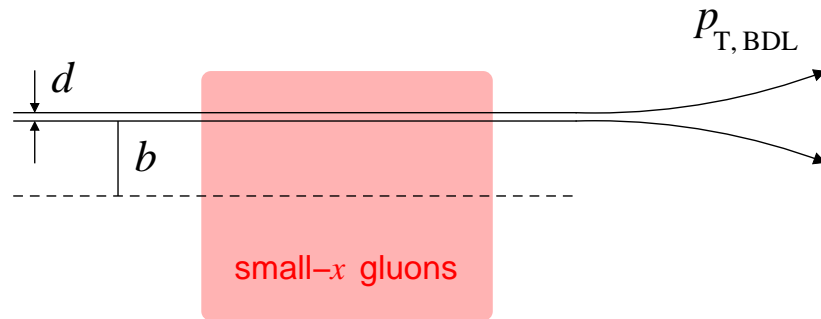


- Construct $\Gamma^{dp}(b)$ from dp cross section in leading $\log Q^2$ approximation
- Strong rise of gluon density at small x (DGLAP evolution)!
- BDL reached in interaction of small dipole at small x and central impact parameters
- Color factor: Cross section for gg dipole larger than for $q\bar{q}$ by factor $9/4$



- Black-disk limit: Space-time picture

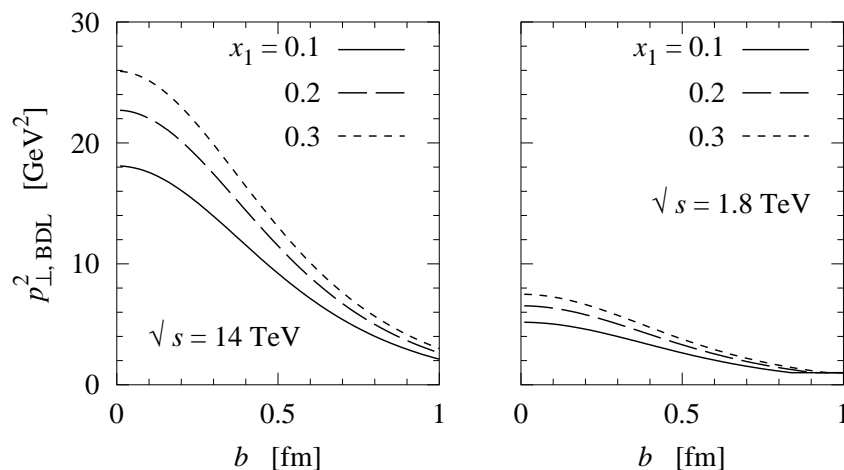
[Frankfurt, Strikman, CW 03]



- Dipole propagates through dense medium of small- x gluons

- Multiple inelastic interactions (splittings)

- BDL: High- p_T components in dipole wave function interact with same strength as low- p_T



→ Enhancement of high- p_T in final state (forward particle production)

Here: Dipole in projectile proton
(momentum fraction x_1)

- Implications of BDL for high-energy pp/pA collisions

[→ Talk by M. Strikman]

- BDL reached in interactions of leading partons ($x \sim 0.1$) in central pp/pA collisions at LHC
- Leading partons acquire large transverse momentum $\sim p_{\perp, \text{BDL}}$, increased energy loss
- Qualitative changes in hadronic final-state:
 - Increased p_T of forward hadrons
 - Reduced multiplicities, etc.

... Can be studied by selecting central pp events through trigger on hard QCD process (dijet)

Summary

- Dipole–proton cross section from QCD factorization of inclusive DIS increases strongly at small x (DGLAP evolution)

$$\sigma^{dp} \propto d^2 x G(x, Q_{\text{eff}}^2 \sim d^{-2})$$

- Transverse spatial distribution of gluons from t –dependence of hard exclusive processes
- Black–disk limit (BDL) reached in central dipole–proton collisions at LHC energies

$$\Gamma^{dp}(b) \rightarrow 1.$$

... New regime of strong interactions ... can be probed at LHC!